EOARD contract FA8655-05-C4082

AN/FMQ-12 Digital Ionospheric Sounding Systems in Greenland

Final Report Phase III

covering the period 04 April 2007 through 03 April 2008

prepared by
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I Technical Report

The three digisondes located at the Greenland west coast sites, Narsarsuaq, Kangerlussuaq and Qaanaaq, were operated according to the EOARD contract. The instruments were operated under routine supervision and with routine maintenance by on-site personnel and staff from the University of Massachusetts, Lowell. No substantial technical problems were reported. The acquired data were processed on site and accessed via electronic communication links (internet connection) by AFRL and DMI staff. Backup copies of the data (CD-ROMs with sequences of daily files) were shipped to DMI.

Verification of data quality and accuracy has been done throughout the reporting period. Comparison of plasma density profiles obtained from digisonde and incoherent scatter radar measurements (both instruments are co-located at the Sondrestrom Research Facility) has shown good agreement between coincident observations from the two different sensors.

For initial visualization and analysis of digisonde data we use software developed and made available by the Center for Atmospheric Research, University of Massachusetts Lowell, namely the SAO Explorer (v. 3.4.03b) and Drift Explorer (v. 1.2.4).

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14. ABSTRACT

This report results from a contract tasking Danish Meteorological Institute as follows: The Grantee will study the polar ionosphere and develop data to correlate variances of space and atmospheric electromagnetic transmission as well as operation of space and airborne systems. The contractor will use the existing US Government Furnished Digital Ionospheric Sounding System (DISS or three AN/FMQ-12 ionospheric sounders) in Qaanaaq 77o28'N 69o13'W, Sondre Stromfjord/Kangerlussuaq 66o55'N 51o07W, and Narsarsuaq 61o20'N 45o21'W Greenland. These sounders have been delivered, installed, and operated under State Department Permit to Operate, Permit Number 512-202, valid from 01 Jan04 through 31 Dec 2009 titled "Polar Cap and Auroral Ionospheric Dynamics - Satellite and Ground-Based Studies." At the conclusion of this contract, all US Government Furnished Equipment will remain the property of the United States. DMI will provide the following resources and services:

1) Operate the DISS in a combination of routine and special purpose modes:
2) Support the maintenance of DISS in cooperation with AFRL/VSBXI and the primary maintenance contractor. Specifically, DMI will
3) Analysis and quality control of the data obtained from the DISS and other sensors.
4) Provide copies upon request of any or all, raw or processed data gathered by the DISS in a form electronically compatible with AFRL/VS.

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II Scientific Report

A Comparison between Total Electron Content (TEC) inferred from ISR and DISS

The total electron content (TEC) is not directly measured by the digisonde because the digisonde cannot profile the electron density distribution where it decreases with increasing height. The digisonde TEC is a product derived from the measured part of the density profile (where the density increases with height) complemented by model assumptions. In contrast, the incoherent scatter radar measures locally the plasma density at many closely spaced points along the radar beam and can in principle determine the full profile and then integrate it to determine the TEC. However, the lowest and the highest altitudes (where the plasma density is low and the return signal strength is small) often bear large uncertainties which contribute to uncertainty in the TEC.

We have compared the TEC inferred from spatially and temporally coincident digisonde and incoherent scatter radar (ISR) data. Our reference instruments are the co-located Sondrestrom ISR and digisonde facilities. We have selected the two-month time interval September/October 2002. The geomagnetic conditions were mostly quiet, but a few storms occurred (see the *Dst* index in Fig.1). The *Dst* index is a measure for the intensity of the symmetric ring current which is considered a good proxy for the magnitude of a magnetic storm.

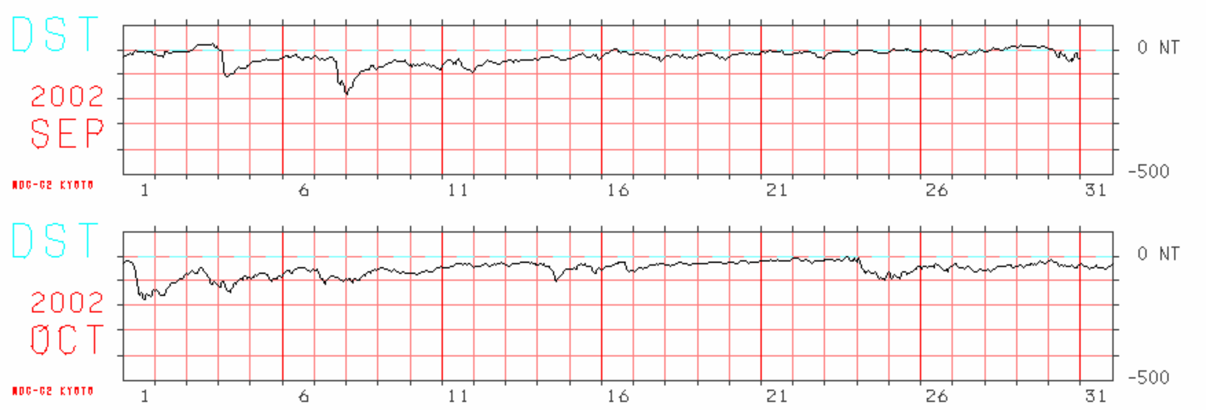


Figure 1. *Dst* index during September and October 2002. One strong storm occurred on September 7/8 and another one on October 1/2. Several weaker storms occurred over the whole period. The *Dst* data and the figures were provided by the World Data Center for Geomagnetism, Kyoto, Japan.

We extracted all available coincidences between valid TEC numbers inferred from digisonde measurements and from ISR data. The ISR measurements were integrated from 200 km to 550 km altitude, i.e. they provide a lower limit to the true TEC. The error due to underestimation is usually small since the peak density is paractically always between 200 and 550 km. ISR data were screened such that only data points with errors less than 10% were retained. We then computed the ratio between TEC obtained from the digisonde and the ISR and plotted it in logarithmic scale against the TEC measured with the ISR. The latter is considered the more reliable number. Fig.2 shows the result. It is obvious that the TEC ratio is not centred around 1.0 (log10 around 0.0) which would mean that values inferred from the digisonde and the ISR are equal on the average. Instead, in the majority of cases the TEC inferred from the digisonde is smaller than from ISR, mostly 1-3 times smaller.

At very small TEC values (TEC below about $4*10^{16}$ m^{-3}) we find many cases of larger digisonde TEC than ISR TEC, but we need also have in mind that small errors on small values can result in a large ratio. The higher the TEC ISR numbers run the less often occur large TEC overestimates by the digisonde and the more often underestimates the digisonde the TEC. At the largest observed TEC ISR values (TEC exceeding $24*10^{16}$ m^{-3}) the digisonde practically always underestimates the TEC.

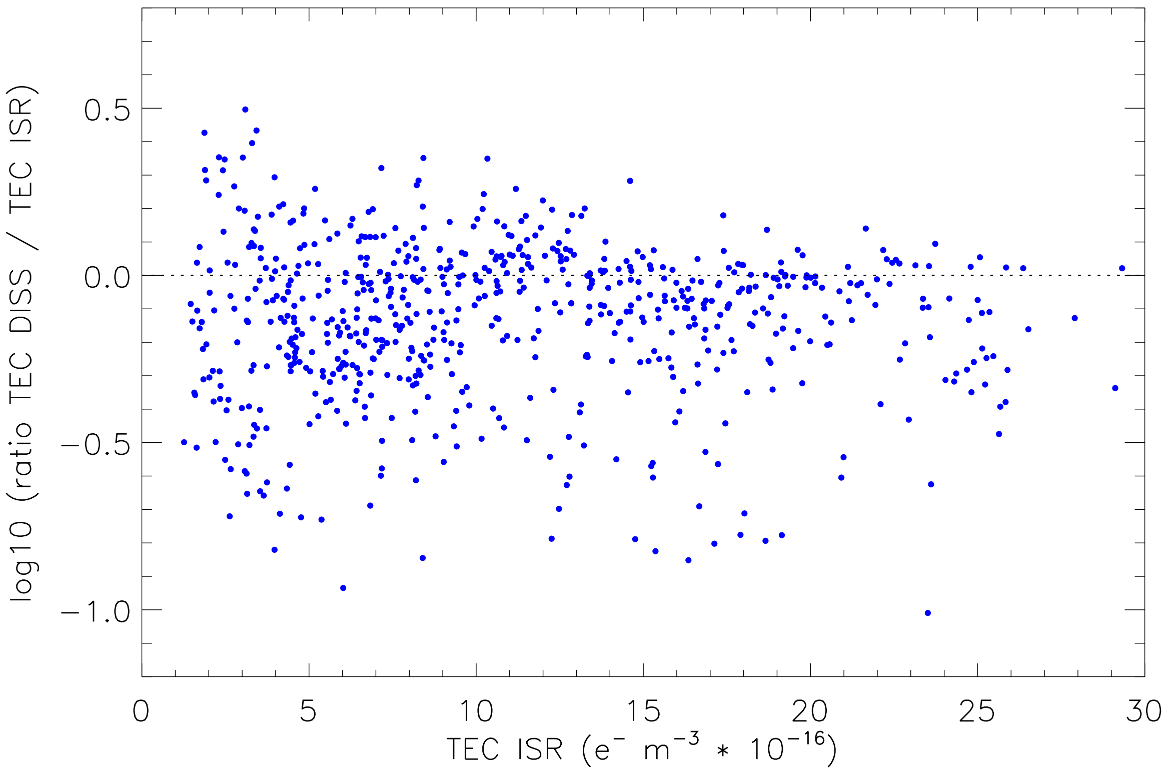


Figure 2. The TEC ratio between digisonde (TEC DISS) and incoherent scatter radar measurements (TEC ISR) in logarithmic scale ordered after increasing TEC ISR values. 671 data points from September-October 2002 contribute to this figure. The ratio is systematically biased by frequent underestimation of TEC DISS. Overestimates of TEC DISS are fewer and occur practically never at the highest TEC numbers.

The TEC is an important parameter which influences satellite-ground and satellite-satellite communication quality (in the latter case only if the radio wave traverses a large part of the ionosphere). The TEC is also an important parameter for assessing radio wave absorption. It is therefore desired to have some knowledge about the probability that the TEC numbers inferred from deviate from the true TEC, and if yes, in which systematic (or non-systematic) way. This investigation is a first step toward this goal.

B Comparison of electron drift patterns: Digisonde vs. Incoherent Scatter Radar

At ionospheric altitudes exceeding about 100 km the electron drift is nearly a Hall drift. That means, electric field and electron drift form nearly a right angle the orientation of which is such that in the northern high-latitude hemisphere a northward pointing electric field results in a westward electron drift. We have now started to compare electron drift patterns in the ionosphere derived from Kangerlussuaq digisonde Doppler shift measurements with electric field data inferred from the Sondrestrom Incoherent Scatter Radar (IST).

Below we display data from the night August 14-15, 2002 of the ionosphere above the Sondrestrom ISR. The top panel shows the electric field inferred from the ISR, decomposed into eastward (red) and northward (blue) pointing components. Note that "east" and "north" mean corrected geomagnetic directions. At Kangerlussuaq geomagnetic north is found about 27˚ counterclockwise from geodetic north.

We consider now two time samples, 22:20 UT and 23:20 UT (marked by vertical dotted lines). At 22:20 UT the electric field is nearly geomagnetically northward oriented. At 23:20 it points about 25˚ to the west of geomagnetic north. The associated electron drift should thus be directed toward 90˚ and 115˚ west, respectively.

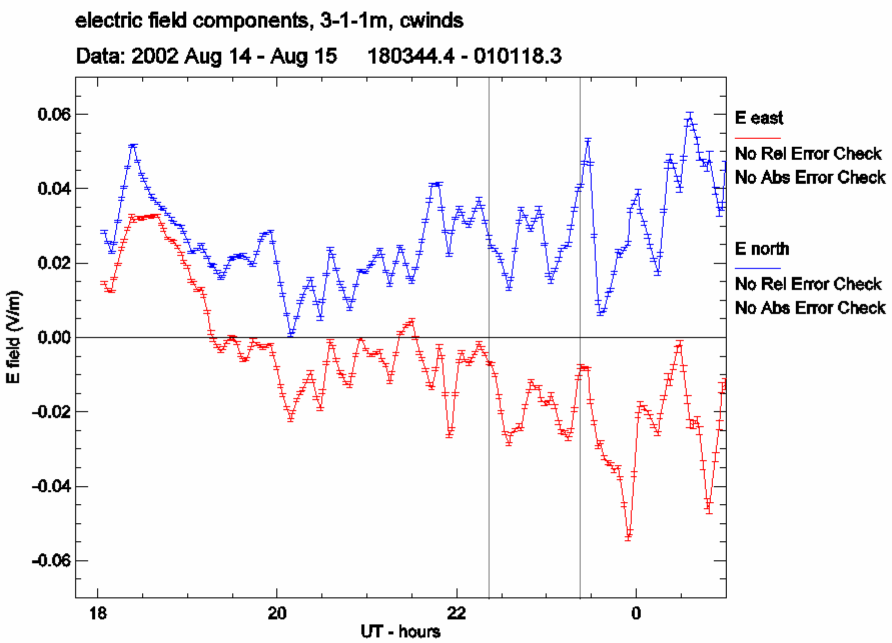
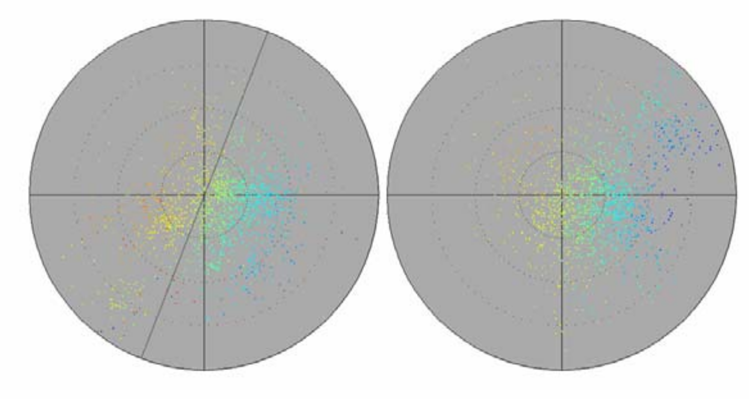


Figure 3. Ionospheric electric field above the Sondrestrom incoherent scatter radar (ISR), decomposed into geomagnetic northward and eastward components. The dotted vertical lines mark the times of the skymaps shown in Figure 4.



22:20 UT 23:20 UT

Figure 4. Skymaps of Doppler shift patterns inferred from the digisonde co-located with the ISR in Sondrestrom. The left map refers tp 22:20 UT, the right one to 23:20 UT. The oblique dotted line in the left skymap shows the separator between generally positive (green-blue) and generally negative (yellow-red) Doppler shofts. In the right skymap the separator falls on the north-south line and is therefore not plotted.

Figure 4 shows skymaps from the Kangerlussuaq digisonde at these two times. In both cases we see a positive Doppler shift (green to blue colors) mainly in the eastern half and a negative Doppler shift (yellow to red colors) in the western half. This translates into a drift from east to west in general. In the left-hand skymap (22:20 UT) the separator between positive and negative Doppler shifts is not exactly north-south aligned, it is rotated about 20˚ to the east, meaning an average drift direction of only 70˚ west instead of 90˚. In the right-hand skymap (23:20 UT) the separator between positive and negative Doppler shift is nearly north-south aligned which translates into a 90˚ west direction instead of the expected 115˚.

The most reasonable explanation for this discrepancy is the fact that the local electric field above Sondrestrom changes rapidly in time (as is seen from the top panel), and it may have been rather non-uniform over the field-of-view of the digisonde. One might think of another explanation, namely that collisions of electrons with the neutral gas are not negligible which results in a drift which is not perfectly a Hall drift (i.e., not 90˚ rotated). However, from the 20˚-25˚ deviation we can infer that the electron collision frequency required would amount to about at least one third of the electron gyro frequency, a value, which is too high by at least an order of magnitude (more likely two) for altitudes exceeding some 100 km.

We can as a minimum draw the conclusion that in the cases shown here the electron drift inferred from the digisonde is in good (but not excellent) agreement with ISR observations.

Hans Gleisner, 2008-04-21